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ESL Math and Science for High School Students: Two Case Studies

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Abstract

This paper documents the experiences of the author in implementing a content-ESL program for high school mathematics and science. It consists of case studies of one ESL-math class and one ESL-science class. Data were collected through the use of a "Word Problem Procedure" for math and a "Scientific Method Procedure" for science. These procedures invite the use of learning strategies and enable instructors to collect data on the linguistic, academic, and strategic aspects of content-ESL. The following questions are investigated: (1) What are the linguistic demands of mathematical and scientific content? (2) How is student acquisition of this content assessed? (3) How can teachers provide contexts for students to utilize learning strategies in acquiring this content? and (4) How is the role of learning strategy instruction in this acquisition process measured? Answers to these questions lead to recommendations regarding the education of language minority high school students.

Introduction

Content-English as a second language ("content-ESL") programs have become a widely-accepted alternative in the education of language minority youngsters enrolled in American schools. Curricula are designed to integrate academic content and language learning in a manner that is sensitive to the linguistic and ethnic backgrounds of diverse student populations. The ultimate goal is to enable students to acquire academic language skills while mastering the content necessary for success in the mainstream.

At the same time, there has been a growing national emphasis upon mathematics and science education spearheaded by the reforms envisioned by the National Council of Teachers of Mathematics (NCTM) (1989), the American Association for the Advancement of Science (AAAS) (1989; 1991), and the presidentially-mandated *America 2000* (1991). These reform programs place great emphasis upon scientific and mathematical literacy. Science and mathematics classrooms will emphasize communication and discourse in the context of mathematical and scientific problem solving. For example, NCTM (1991, p. 35) recommends that mathematics teachers "orchestrate discourse by posing questions and tasks that elicit, engage, and challenge each student's thinking, and asking students to clarify and justify their ideas orally and in writing." While promising to be more relevant and inviting to students of all ethnic backgrounds, such classes will also be more challenging in terms of the language skills students will need upon entry.

Secada (1991) has warned that efforts to educate language minority students will be in vain unless language teachers and content educators begin to pay serious attention to each other's reform agendas. The content-ESL teacher will need to teach the content and skills presupposed in reformed mainstream classes, while mathematics and science teachers will need to become attuned to the special needs of language minority students and be prepared to plan their instruction accordingly.

This goal poses obvious challenges with respect to the education of students of limited-English proficiency. How will these students develop the linguistic proficiency necessary to deal with classes that presuppose advanced communication skills? What preparation will teachers need to provide effective instruction? How will schools have to change in order to accommodate cooperative relationships between language and content teachers? What kinds of research will help to facilitate these new relationships?

This paper examines the author's experiences teaching ESL math and ESL science in a high school setting. It investigates questions related to language development, content learning, and the role of learning strategies in ESL math and science classes. In the concluding section, it returns to the challenges posed above and makes recommendations with regard to the institution and maintenance of content-ESL programs.

Background

The author is employed by a small, suburban, culturally diverse school district. His duties are divided between teaching high school English as a second language (ESL) classes in math, science, and social studies, and serving as a resource for fourth through tenth grade ESL teachers with similar content-ESL duties. The dual nature of this position has provided him with a unique perspective on the day-to-day teaching of content-ESL. The opportunity to "practice what he's been preaching" has led him to conduct the classroom-based research reported here.

Characteristics of school district and high school

A total of 15,483 students were enrolled in the county's schools in the 1991-92 school year. Of this number, 15.5 percent were language minority students who spoke 52 different languages. Of these students, 71 percent were Spanish speakers who came primarily from El Salvador and Bolivia. The total school population at the case study high school was 1,460 students on September 30, 1991. Of these students, 254 (17 percent) received special services through the English as a Second or Other Language/High Intensity Language Training (ESOL/HILT) program. The majority of these students were of Hispanic origin (67 percent), with Vietnamese students being the next largest group (12 percent).

Students in the HILT program at this high school receive five periods of ESOL/HILT classes over three proficiency levels. HILT A is for beginners, HILT B is for intermediates, and HILT-Extension is for advanced students. HILT A students typically take HILT Social Studies and HILT Math, while HILT B students typically take HILT Science and a credit course in HILT General Math taught by a certified math teacher. HILT-Ex students typically take two periods of language arts instruction and one period of HILT Social Studies per day, and fill out their schedules with mainstream content classes. This instruction incorporates language arts (speaking, reading, writing), social studies, math, and science. All HILT classes are taught by HILT teachers who are certified in ESL and who are eligible to receive special training in content-ESL, learning styles, multicultural education, and the implementation of learning strategy instruction in the content areas.

Since 1976, the district has used local and Title VII funding to create and maintain an Intake Center, the HILT program, parent training, special needs and dropout prevention programs, and the Cognitive Academic Language Learning Approach (CALLA) for Mathematics and Science. The case study high school has the largest language minority population in the district. It employs two bilingual staff members to serve the Spanish- and Vietnamese-speaking populations, and has an active dropout prevention program. It employs 11 HILT teachers, most of whom teach HILT Social Studies in addition to their language arts classes. Two teachers, including the author, teach HILT A Math, while three teachers, including the author, teach HILT B Science. The students in the HILT B Science class taught by the author participate in the "Partners for Success Program," a special dropout prevention program administered through the County Special Needs Office. Classes for these students are limited to 15 students, and they receive one period of counseling per week to help them build self-esteem and personal responsibility.

These efforts to assist language minority students make the school and the school district exemplary at the programmatic level discussed by Lucas, Henze, and Donato (1990).

The Cognitive Academic Language Learning Approach (CALLA)

In 1988, the school district received a Title VII grant to initiate a CALLA for Mathematics project to be implemented in grades four through ten at schools with significant numbers of language minority students. The CALLA approach is an instructional system developed by Chamot and O'Malley (1986) that prepares language minority students for mainstream classrooms. In order to do this, it integrates three basic components: a content-based curriculum; academic English language development; and direct instruction in learning strategies. It is the most widely recognized of the various models that have recently been developed for content-ESL (see Spanos, 1990, for a review and annotated bibliography of content-ESL programs), and has been used as the theoretical and developmental basis for several federally- and locally-funded curriculum development projects in recent years.

In 1991, another Title VII grant was obtained to implement a CALLA for Science project at a middle school with a growing population of language minority students that had not been previously served. The district provides additional support which allows CALLA for Science to be available at other district secondary schools.

The CALLA approach adopts Cummins' (1992) distinction between cognitive academic language proficiency and basic interpersonal communication skills. It recognizes research evidence that it takes second language (L2) learners a considerably longer time (five to seven years, according to Cummins) to approach grade norms in L2 academic content classes than it takes for them to develop basic conversational skills. The challenge for educators of language minority students is to develop programs and instructional approaches that advance them to grade level as quickly as possible. In the case of the newly arrived student who enters high school at age 15 or older, this is a daunting challenge indeed. Research by Collier (1987), for example, indicates that it takes up to eight years for children arriving at ages 12-15 to reach grade norms.

Classes at district schools follow a curriculum developed along the lines suggested by the CALLA approach. HILT Math is designed for students who have had little or no previous schooling in mathematics or who exhibit third to fifth grade math skills. Students are placed in HILT Math on the basis of their performance on a basic computational skills test when they enter the school system. This instrument tests student ability to add, subtract, multiply, and divide whole numbers, fractions, and decimals. Secondary students who score lower than 45 percent on this test are placed in HILT Math.

The primary objective of the course is to prepare students for mainstream mathematics, typically a general mathematics course for HILT students taught by a certified mathematics teacher. HILT Math is taught primarily by HILT teachers, although some mainstream math teachers also teach the course. The HILT Math course bears elective credit at the middle and high school levels.

The course gives students intensive exposure to basic mathematical concepts, relationships, and operations and aims to help them develop critical thinking skills, particularly in mathematical problem solving. In addition, it provides opportunities for students to engage in academic language skills activities such as math vocabulary development and reading and writing practice with mathematical content. Furthermore, it provides training in the development of metacognitive, cognitive, and social-affective learning strategies linked to mathematical content.

The usual course of advancement for entering high school students is that the ninth grader with beginning language skills (grade 0-2 reading ability in English) and a grade below 45 percent on the computational skills test is placed in HILT A Math for one year. From there, the student advances to HILT General Math for the sophomore year, and finally, if successful, enters beginning algebra in the junior year.

The HILT B Science class is designed for students with intermediate language skills. Unlike HILT A Math, students are placed in HILT B Science on the sole basis of HILT B language proficiency, since there is no placement test in science concepts nor are there skills or any prerequisite courses. The primary goal of the course is to teach students basic concepts in physical and life science in preparation for entry into a high school HILT-Ex Biology course taught by a certified science teacher. Students participate in activities designed to develop and practice the language of science, basic science concepts and skills, and specific learning strategies to help them understand, recall, and apply science information and skills.

It is important to note that the CALLA approach is best suited to intermediate and advanced language learners. These include students who have already developed conversational skills, who have exited bilingual programs but need assistance in transferring academic concepts and skills learned in the native language, or who are English-dominant bilinguals who need to develop academic English language skills (Chamot and O'Malley 1992, p. 41). The ideal order in which students take CALLA courses is to begin with science, move to mathematics, and end with a course in social studies (1992, p. 41). This will be important in comparing the classes included here since the math class primarily serves beginning language learners, while the science class serves the recommended intermediate learners.

Rationale for Learning Strategy Instruction

The distinguishing feature of the CALLA approach as compared to other content-ESL approaches is its explicit appeal to cognitive learning theory and its promotion of learning strategies to facilitate the development of academic language skills. O'Malley, Chamot, and Walker (1987) rely upon Anderson's (1985) distinction between declarative knowledge (what we know about something) and procedural knowledge (what we know how to do). While declarative knowledge such as word definitions, facts, and rules may be acquired relatively quickly, procedural knowledge, such as facility in the use of academic language or the application of a mathematical rule, develops gradually and requires extensive practice (Chamot and O'Malley, 1992). One challenge with respect to the education of language minority students is preparing them to express declarative knowledge, acquired either in the first language (L1) or L2 context, procedurally through L2. A crucial factor in effecting this transition, according to Chamot, O'Malley, and their associates, is the explicit and direct implementation of learning strategy instruction.

Whereas the content component of CALLA provides the declarative knowledge that underlies science, mathematics, and social studies, and the language development component provides procedural knowledge such as the use of a prescribed series of steps to comprehend math word problems, learning strategies are taught to students as "declarative knowledge that may become procedural knowledge through practice" (Chamot and O'Malley 1992, p. 44). As students practice learning strategies in the context of academic topics, they are taught the names of the strategies and given practice in their use. It is anticipated that they will develop into autonomous learners who can apply procedural knowledge learned initially as declarative knowledge.

Three categories of learning strategies are taught through the CALLA approach: metacognitive strategies, or the executive strategies that individuals use to plan for, monitor, or evaluate learning; cognitive strategies, or the manipulation of learning materials by reorganization, grouping, and elaboration of new ideas, or the relating of new ideas to prior knowledge; and social-affective strategies, by which the learner calls upon another person for assistance or works cooperatively with others on a common task. Selected learning strategies and definitions adapted from Chamot and O'Malley (1992, p. 55-56) that will be referred to in this study are:

- Advance Preparation: Rehearsing the language needed for an oral or written task (metacognitive strategy);
- Organizational Planning: Planning the parts, sequence, and main ideas to be expressed orally or in writing (metacognitive strategy);
- Selective Attention: Attending to or scanning key words, phrases, linguistic markers, sentences, or types of information (metacognitive strategy);
- Resourcing: Using reference materials such as dictionaries, encyclopedias, or textbooks (cognitive strategy);
- Deduction: Applying rules to understand or produce language or solve problems (cognitive strategy);
- Elaboration: Relating new information to prior knowledge, relating different parts of new information to each other, or making meaningful personal associations to the new information (cognitive strategy);
- Inferencing: Using information in the text to guess meanings of new items, predict outcomes, or complete missing parts (cognitive strategy);
- Questioning for Clarification: Eliciting from a teacher or peer additional explanation, rephrasing, examples, or verification (social-affective strategy); and
- Cooperation: Working with peers to solve a problem, pool information, check a learning task, or get feedback on oral or written performance (social-affective strategy).

Derry (1990) argues that we should distinguish between individual learning tactics and more complex learning strategies that combine several learning techniques. Learning tactics are viewed by Derry as individual processing techniques used in the service of the more complex plans, which she refers to as learning strategies. This difference is central to an understanding of the instruments used in the case studies described below.

The Case Studies

In order to provide a dynamic context for integrating learning strategy instruction with academic language and content instruction in his HILT Math and HILT Science classes, the author has developed a Word Problem Procedure (WPP) for math and a Scientific Method Procedure (SMP). These procedures are presented as worksheets (see "Instruments" section, following), which students complete in cooperative groups of two or three students. They are examples of learning strategies in Derry's (1990) sense of being complex plans for learning. In the course of following the steps, students are invited to utilize both general learning strategies and specific learning tactics as they practice content-specific academic English. The teacher may make the strategies and tactics explicit or may choose to let the students process the content according to the instructions on the worksheets. Once they have discovered strategies and tactics on their own, the teacher can make them aware of what they have done by naming the strategies and inviting students to reflect on their use.

In order to enable students to become aware of the strategies and tactics associated with problem solving and experimentation, the WPP and SMP are supplemented with learning strategy checklists and student self-evaluation forms which the students fill out when they complete classroom activities that use the procedures. The WPP, the SMP, the checklists, and the evaluation forms are thus both teaching tools and data collection instruments that help teachers and researchers investigate questions such as: (1) What are the linguistic demands of specific mathematical and scientific content? (2) How is student acquisition of this content assessed? (3) How can contexts be supplied for students to utilize learning strategies in acquiring this content? and (4) How is the role of learning strategy instruction in this acquisition process measured?

The case studies undertaken in this paper have been prepared to investigate these questions. Separate methods, results, and discussion sections will be presented for both the math and the science classes. The results are presented as a step-by-step analysis of student performance on the WPP and SMP. The results are then discussed in reference to the four questions.

For the most part, the case study data will be drawn from implementation of the WPP and the SMP during May and June 1992 (the preparation period of this study), but will also include data collected throughout the 1991-92 school year for math and science, and from a 1990-91 HILT Math class.

Method: Math Case Study

Subjects

Twenty students were enrolled in HILT A Math in May 1992. Of the Spanish speakers, thirteen were from El Salvador, two from Bolivia, and one from Guatemala. Of the remaining students, two were from Ethiopia (Amharic speakers), one from Somalia (Somalian speaker), and one from Pakistan (Urdu speaker). Four of the students were tenth graders, and the remainder were in the ninth grade. They ranged in age from 14-18 years old. Only two students had been in the class since the first day of school, and the rest had entered at various other points in the school year through entry to the school system at the Intake Center, transfer from another secondary school in the county or elsewhere, or transfer from another class at the project high school. Eight students had entered the class in the third quarter or later, three of whom had been in the class fewer than two weeks. Half of the original class (those who had been in the class at the beginning of the school year) had exited due to a decision to form a new HILT General Math class for the more mathematically proficient HILT A Math students.

The math ability of most of the remaining students and the students who entered after the change was very limited. Few had scored higher than 45 percent on the county math placement test, meaning that they had limited to no competency with fractions, decimals, ratios, and percents. Most could add and subtract whole numbers with some confidence, but few could handle multiplication and division of whole numbers beyond two digits. Four students who had entered the class early in the year (before Christmas vacation) had taken a standardized fourth grade math pre-test which supported the results of the placement test; only one student demonstrated mastery on any of the 12 strands included in the test, and his mastery was limited to whole number addition, subtraction, and multiplication and, inexplicably, to computation with decimals.

Four of the students who entered late in the year (later than February) scored between 45 percent and 55 percent on the placement test. Had they entered in the first semester, they would have been recommended for HILT General Math. These four students came from Somalia, Ethiopia, El Salvador, and Bolivia.

All of the subjects were HILT A students, meaning that their reading ability was below the second grade level. Their writing ability was at the pre-to-simple sentence level and was marked by grammatical, lexical, and mechanical errors. Few students were able to engage in more than the most rudimentary conversational exchanges, and it was evident to the instructor that their aural comprehension skills made it difficult or impossible for them to understand academic discourse delivered in even the most rudimentary lecture style. This fact, coupled with low math proficiency, made it very difficult for them to deal with teacher explanations, textbook explanations, and word problems.

In addition, while not officially confirmed, it was evident that most of the students had had limited or interrupted educations in their home countries. Thus, in addition to their low mathematical and linguistic skills, they were unfamiliar with structured classroom environments. Classroom discipline was a constant problem, and student responsibility in terms of regular completion of in-class and homework assignments was sorely lacking.

Instruments

The Word Problem Procedure (WPP) was developed by the author in the 1990-91 school year as a means of integrating learning strategy instruction and mathematical problem solving. It was inspired by Polya's (1957) four-step procedure (Understanding the problem/Devising a plan/Carrying out the plan/Looking back) and by materials which the author had helped develop while at the Center for Applied Linguistics (Crandall, Dale, Rhodes, and Spanos, 1987). Since limited English proficient (LEP) students need a great deal of support in understanding word problems, steps were added to help them reach the planning and solution stages. In addition to facilitating mathematical performance, the WPP is designed to engage students in an activity that will enable them to practice reading, writing, speaking, and listening, and to learn to use and practice learning strategies and tactics associated with the various steps. The format is as follows:

NAMES

DATE

Word Problem Procedure

1. Choose a partner or partners. Write your names above.
2. Choose a problem. Write the problem in the space below.
3. One student read the problem out loud. Discuss the vocabulary and circle words you don't understand. Write the words below.
4. Use a dictionary for help. Ask your partner or teacher for help.
5. What does the problem ask you to find? Write this below:
6. What should you do to solve the problem? Add? Subtract? Multiply? Divide? Write this below.

7. Solve the problem below.
8. Check your answer below.
9. Explain your answer to your partner(s). Write your explanation below.
10. Explain your answer to the class.
11. Write a similar problem on the back of this page.

The various steps of the WPP make it possible for students to practice academic English, apply mathematical rules, and use learning strategies and tactics in the course of the activity. It also provides opportunities for teachers to be explicit and direct in their instruction and to pinpoint specific strategies and tactics that they wish their students to practice. Students use metacognitive strategies such as selective attention in focusing on unknown words (Step 3) and attending to what the problems ask them to find (Step 5), advance preparation in reading the problem to each other (Step 3), and self-management in explaining the problems (Step 9) or writing similar problems (Step 11). They use cognitive strategies such as resourcing in using their dictionaries (Step 4), and elaboration and deduction in solving the problems (Steps 7 and 8). They use social-affective strategies such as cooperative learning and questioning for clarification in working their way through the various steps. The use of this format thus creates opportunities to introduce and practice learning strategies while solving word problems. In the context of this study, it also makes it possible to analyze student performance in reference to their ability to follow individual steps and sequences of steps, and to learn and apply learning tactics and strategies.

In order to note their perceptions of using the WPP, the students were asked to fill out a Learning Strategy Checklist after each WPP activity and a Student Self Evaluation form at various times in the learning process:

NAMES

DATE

Mathematics Learning Strategy Checklist

There are many ways to solve problems. Check the two or three things that you did most while you worked on this problem. There are no right or wrong answers.

A. I looked for the important words to solve the problem.

B. I read the question carefully.

C. I remembered how I solved other problems like this one.

D. I did the problem in my head because it was easy.

E. I made a picture in my head or I drew a picture.

NAME

DATE

Math Student Self Evaluation

These are two important things I learned in math today/this week/this month:

1.__________________________

2.__________________________

This is an easy problem for me:

This is a difficult problem for me:

I need more help with:

This is how I feel about math today/this week/this month: (circle the words that are true)

successful, confused, relaxed

interested, bored, excited

happy, worried, upset

This is where I got help: (circle the words that are true)

my teacher, my friend or classmate, my parents

Procedures

The students were given the WPP six times in May and June 1992. The 44 minute classes began with a brief review of the homework assignment, which dealt with the operations needed to do the word problems to be practiced that day. The remainder of the class was devoted to completion of the WPP, the Learning Strategy Checklist, and the Student Self Evaluation sheets. The students were instructed to pair off and to solve word problems selected by the instructor from a word problem review sheet that was selected from Shea (1991). As students worked on the WPP, the instructor circulated and provided assistance as requested. Spanish-English dictionaries were available for the Spanish speakers. Since none of the non-Spanish speakers had bilingual dictionaries, the author urged them to pair off with Spanish speakers so at least one pair member had L1 lexical assistance.

The following word problems were used in the six sessions. An indication of the computational objective covered by each is in parentheses.

1. Sam's truck weighs 4,725 pounds. The truck can carry 7,500 pounds. What is the total weight of the

truck and full load? (addition of whole numbers)

2. A factory that makes electronic equipment produced 3,048 VCRs in June. In July, the factory produced 2,986 VCRs and another 2,809 in August. How many VCRs were produced in the three months together? (addition of whole numbers)
3. Last week we drove to Detroit. At an average speed of 50 miles per hour, the trip took 4-1/2 hours. How far was it? (multiplication of whole and mixed numbers)
4. For the first four months of the year, rain fell as follows: 2-1/2 inches, 3-1/4 inches, 1-1/8 inches, and 1-1/2 inches. What was the total rainfall for these four months? (adding mixed numbers with unlike denominators)

The instructor used two of the six sessions to model the WPP. This was necessary because several students had recently entered the class and had not yet seen it. The four examples selected for discussion are from the last four sessions, by which time most students seemed to be comfortable enough with the format to get through steps one through seven of the WPP, the checklist, and the evaluation form in one class period.

The author examined the student worksheets and selected responses related to the 11 steps in the WPP. The results cited below also draw from the instructor's notes and recollections from the sessions, and from information provided by the students on the checklists and evaluation forms. Errors in English, mathematical representation, and computation are left intact in the examples presented below.

Results: Math Case Study

Step 1 (Choose a partner). Students tended to choose partners who sat nearby. The two Ethiopian boys tended to work together, while the Pakistani girl, who was extremely shy and passive, always stayed in her seat and worked with a boy from El Salvador who had sat behind her throughout the year. The only non-Hispanic student who demonstrated much group mobility was the boy from Somalia, who was the most ambitious and cooperative member of the class.

Occasionally certain students were directed to work together, but only if they displayed a reluctance to attend to the task. The instructor was surprised at how long it took students to form pairs and begin work. Even after pairing up, some pairs would take 5-10 minutes to begin serious consideration of their word problems.

Step 2 (Choose a problem and write it). Simply copying the word problems from the review sheet was difficult for many of the students. Their work was marked by poor handwriting, spelling errors, sentence fragments, run-ons, and mechanical errors involving capitalization and punctuation. It was clear that their written English was at a very rudimentary level and that they needed extensive practice with basic handwriting. A typical example of a student attempt to rewrite a problem is the following:

Last week we drove to Detroit. At a speed of 50 miles per hour. the trip took 4-1/2 hours. How far was the trip to Detroit? (rewrite of Problem 3)

Step 3 (Read the problem out loud. Find difficult words). It was difficult to convince students that they should take turns reading the problem to each other. Even after the instructor selected two students to model the practice for the whole class, most pairs still refused to read aloud. However, they did enjoy circling or underlining words they did not understand and writing them in the space provided. Some of the items selected from the word problems were the following:

Problem 1: weighs, carry, load

Problem 2: factory, equipment, makes, were, produced

Problem 3: drove, average, took, far

Problem 4: fell

Eight of these 13 words are verbs. Two of the verb forms are irregular past tenses (took, fell) of verbs which students had probably already studied. One of the forms is the past participle (produced), which students did not recognize as part of the past passive indicative form (were produced). The rest are probably new or forgotten vocabulary.

Step 4 (Consult with a dictionary, partner, or teacher). It became obvious that students had had little or no practice using bilingual dictionaries outside of their math class. Even though the instructor had plenty of bilingual dictionaries prominently displayed on his desk, students were reluctant to take advantage of them. When they did, they demonstrated a lack of basic dictionary skills. For example, they did not know that they could go from English to Spanish or back. Some students were not even aware that the dictionaries were arranged alphabetically. While not confirmed, the instructor also suspected that some students had never even used an L1 dictionary.

The more skillful students tended to carry the load for their partners in consulting the dictionaries or asking the instructor for assistance. There was also quite a bit of cross-pair discussion, with weak students from one pair consulting with the better students from others.

Step 5 (Write the question). Students were not initially aware that the word problems ended with a question. Once they were, Step 5 became a routine matter of finding the question and copying it. As with Step 2, students made copying errors such as omitting question marks and other punctuation, or writing puzzling statements. For example:

What is carry (Problem 1)

What are you doing the factory (Problem 2)

How many VCRs where produced in the 3 monts to gether? (Problem 2)

Students who wrote the first two examples ignored the questions at the ends of the problems altogether, seeking instead to write their own questions. The last example indicates difficulty in simply copying the question in Problem 2.

Steps 6 and 7 (Find the operation and solve the problem). There were numerous cases of incorrect selection and application of mathematical operations, incorrect representations of the problems, and computational errors. For example:

(Problem 1) 4,725 x 7,500 = 31,500

(Problem 3) 50/1 x 4 -1/2 = 50/1 x 2/9 = 100/9 = 11-1/9

(Problem 4)

2-1/2 = 4/8
1-1/8 = 1/8
1-1/2 = 4/8
4-9/8 = 1-1/8

The first example is an incorrect selection of a mathematical operation: they should have added. The second misrepresents 4-1/2 as 2/9 when it should have been 9/2. In the last example, the students correctly added the whole numbers, found a common denominator for the fractional parts of the mixed numbers, correctly added the common fractions, and converted the sum into a mixed number. The error lies in the fact that they failed to add the sum of the whole numbers (4) to the sum of the fractions (1-1/8) to get a result of 5-1/8.

Despite committing errors such as these, students had more success completing Steps 6 and 7 than any of the other steps of the WPP. The reason is probably that they understood that they needed to compute an answer, and that they needed to determine which mathematical operation had to be employed. Another possibility is that, once one student knew what to do, the information tended to become public knowledge through cross-pair communication.

Few pairs wrote more than a single word for an operation in completing Step 6, although two students did correctly write "multiply and divide" when attempting Problem 3. These students multiplied 50 miles per hour times 4-1/2 hours to get 450/2 and then divided to get the correct answer, 225 miles. They did not, however, indicate how they had converted the mixed number (4-1/2) to the improper fraction (9/2) to get the second factor for multiplication.

Step 8 (Check the answer). Few pairs were successful in checking their answers unless the instructor supplied them with instructions. The instructor frequently reminded students that they could check addition by subtracting and vice versa, and that they could check multiplication by dividing and vice versa. When they did manage to check their answers, pairs tended to do so correctly and with a certain amount of pride, showing their papers to the instructor or requesting to write their work on the board.

Steps 9 and 10 (Explain orally and in writing). It was difficult for students to give a coherent verbal or written English explanation of their work. A typical response was to simply write the numerical answer from Step 7 along with a statement such as: "This is the answer to the problem." Some of the more interesting written explanations follow:

> I assembly together. and I get this count it is 12,225 I think it is the car it goes two trip first one carry 4725 and second carry 7,500 after that I use add (Problem 1)
>
> I added 3 months of sales together to get the answer. (Problem 2)
>
> first we saw the problem and them we thought about the problem. If the truck weight 4,725 pounds and can carry 7,500 pounds all we have to do is add. (Problem 1)

Extended responses such as these suggest that the students were developing the ability to explain their work in English, particularly when they were confident that they had solved the problem correctly.

Step 11 (Write a similar problem). The initial response to this step was to simply copy other problems from the review sheet or any other materials or texts at hand. (Perhaps they believed that all word problems were similar—hard!). Or, perhaps not understanding what “similar” meant, they were groping for the most convenient written response. Whatever the case, upon noticing their difficulties during the first WPP session, the instructor spent the next class period teaching the students the difference between similarity and sameness. They were instructed to change numbers, names, and situations which appeared in sample word problems. But they were not allowed to change the mathematical operation. This exercise resulted in problems which were similar but not exactly the same. When satisfied that enough students grasped the distinction, the instructor had them attempt Step 11. Most students were still unable to take the step without coaching by the instructor, but the following are some of the more interesting results:

> Delmis wieght 145 pound, and Ali wiegh 150. What is the when we together 145 is Delmis and Ali is 150? (Problem 1)
>
> Sam's truck weight 2,354 galon. The truck can carre 1,453 galon. What is the total weight of the truck and full load? (Problem 1)
>
> Nora weighs 145 pounds and Noe weighs 135 pounds How many pounds Nora and Noe weighs together (Problem 1)
>
> Nora's airplanes weighs 3263 pounds. the airplanes can carry 2,725 pounds. What is the total weight of the airplane and full load? (Problem 1)
>
> My brother weighs 155 pounds and he can carry 125 how mus dos he weighs together. (Problem 1)

A factory produced 300 tables in September and 235 tables in May. How many tables were produced in May and September? (Problem 2)

The first five examples indicate that the writers understood the concept of similarity, even if their writing contained linguistic and factual errors. Each example uses addition, but the numbers, names, and situations have been changed, sometimes with odd results such as the second and fourth examples. These results provided opportunities for the instructor to correct errors based upon student-generated text. The final example is remarkable because the student writers extracted words and phrases from Problem 2, changed the numbers and names of the months, and came up with an error-free result.

Discussion: Math Case Study

The results of the WPP sessions reveal limitations in language usage, mathematical skill, and the ability to engage in purposeful classroom behavior. On the other hand, there are indications that students can overcome these limitations. The following discussion concentrates on aspects of language development, math learning, and learning strategy instruction revealed in the WPP sessions, which seem to be evidence for student progress. The discussion is organized according to the four questions posed in the introduction to the case studies.

What are the linguistic Demands of the Mathematical Content?

The word problems that the students attempted were not complex from either a linguistic or mathematical standpoint. None contained extraneous or misleading information, the vocabulary was basic and only the simple present and simple past tenses were used. In addition, each problem had a clearly recognizable question at the end which represented what the students needed to find out. The problems dealt exclusively with basic operations involving whole numbers and fractions. Furthermore, since the instructor cast the WPP sessions in the context of a course review, the students could guess which operations to apply.

Use of the WPP illustrated how students with limited language ability and mathematical knowledge can be taught an approach to word problem solving. Although they had trouble identifying crucial information and explaining their solutions, there were signs of progress. In the examples given for Steps 9, 10, and 11, we saw that some students were able to express their reasoning and mathematical knowledge even though their writing and speaking was marked with linguistic errors. This enabled the instructor to identify and correct the linguistic difficulties, and to assess the students' mathematical knowledge.

In reference to the linguistic difficulties, we must recognize that language minority students are not alone in having difficulty with the language of word problems. The National Council of Mathematics (1989; 1991) has identified "mathematics as communication," particularly as related to problem solving, as an area for curricular reform. As documented by Spanos, Rhodes, Dale, and Crandall (1988), however, language is a barrier for language minority students because they are limited both in basic language proficiency and in the special mathematics register. Thus, the challenge to the ESL math teacher is one of teaching both the basic and special language in ways that are mathematically and linguistically sound. For beginning students such as those included in this study, it is important to select carefully or design word problems with specific objectives in mind. If we are trying to help beginning students develop reading, writing, speaking, listening, or resourcing skills, it is better to keep the math content simple and the math objectives identifiable as we increase the linguistic load. This was particularly evident in the student responses selected for Step 11. The students clearly understood the mathematical concepts involved and were, therefore, confident enough to write their own examples of problems involving these concepts.

On the other hand, if we are trying to help students develop math skills, then we should keep the language simple while increasing the complexity of the math. This was not attempted in the author's 1991-92 classes, but it was used in 1990-91 when there were students in the HILT A math class that had a higher level of math ability and who needed a greater challenge. The complexity of the math was increased in a variety of ways such as using multi-step problems.

How Is Student Acquisition of the Math Content Assessed?

By keeping the language of the word problems simple, we can assess student ability to apply the math concepts and skills through a performance-based approach to assessment such as the one advocated by Stenmark (1989). This was particularly evident in the responses to steps nine and ten, where students had difficulty expressing themselves but, nonetheless, managed to communicate how they had solved the problems. When the Somalian student wrote: "I assembly together and I get this count it is 12,225" in explaining the solution to Problem 2, he was struggling to express the knowledge that addition of the two whole numbers was the way to solve the problem. When he wrote "I think it is the car it goes two trip first one carry 4725 and second carry 7,500," he was betraying a misunderstanding of the meaning of the problem. This made it possible for the instructor to praise the correct solution while correcting the semantic misunderstanding and the lexical and grammatical mistakes.

An example from the author's 1990-91 class is also instructive here. A pair of El Salvadoran students was asked to solve a problem which involved dividing 1,391 by 9. One student's verbal explanation of how he correctly solved the problem was audiotaped and proceeds as follows:

The answer is 154 with remainder 5.
9 times 1 equals 9; 13 minus 9 equals 4.
9 times 5 equals 45; 49 minus 45 equals 4.
9 times 4 equals 36; 41 minus 36 equals 5.
154 times 9 equals 1,386; 1,386 plus 5 equals 1,391.

The student's written version with the author's attempt to explain each step in parentheses is as follows:

1391/9 (1391 divided by 9)
49 (9 times 1 is 9; 13 minus 9 is 4; write the 4 and bring down 9)
41 (9 times 5 is 45; 49 minus 45 is 4; write the 4 and bring down 1)
5 (9 times 4 is 36; 41 minus 36 is 5; write the remainder, 5)

This explanation is remarkable for two reasons. First, it demonstrated a command of mathematical language that went beyond anything the student had been able to produce in ordinary conversational exchanges. Second, it indicated that the student had prior knowledge of a different method for doing division than the one the instructor was teaching. Instead of finding the quotient by asking how many times 9 went into 13, 49, and 41 respectively and multiplying and subtracting until a remainder was reached, he found the quotient by asking how many times the divisor could be multiplied without exceeding 13, 49, and 41, and subtracted until a remainder was found. He did not think in terms of division, appealing instead to multiplication and subtraction. After multiplying and subtracting in his head, he wrote the differences and brought down the next digit from the dividend. By asking the student to express himself orally, the instructor was able to assess both the student's mathematical knowledge and his ability to express that knowledge in English.

How Can Teachers Provide Contexts for Students to Utilize Learning Strategies in Acquiring this Content?

The WPP has been described as a learning strategy in Derry's (1990) sense of being a complex plan that combines several learning techniques. Thus, it is by definition a method for providing multiple opportunities for the use of learning strategies and tactics. Use of the Learning Strategy Checklist and the Student Self Evaluation form verified student use of various strategies and tactics and their ability to evaluate their own math performance. By examining the checklists and evaluation forms and questioning the students about their responses afterward, the author was able to determine which strategies and tactics they had used and how useful they felt they were. For example, following the WPP activity involving Problem 1, the author noticed that one of the pairs that successfully solved the problem had circled items A, B, C, and D on the checklist. He then asked the students which words they had found important (regarding item A) and when they had done similar problems (regarding item C). The students replied that the word ‘total’ gave them the clue that they needed to add to find the answer, and that they were familiar with determining weight in contexts such as visits to the grocery store. When asked why they had circled item D ("I did it in my head.") (a puzzling choice given that they had done their computation on the paper) they replied that they had figured out what to do by guessing that they needed to add. What had gone on in their heads was the inferential reasoning not the actual computation.

The importance of the questioning session is that the students were given an opportunity to reflect upon their performance and to internalize the strategies and tactics they had used. The evaluation form was also useful in this regard because the instructor could conduct a discussion with the students in reference to their personal assessment of what was difficult, what was easy, what they needed help with, and how they felt about their performance. In one questioning session, for example, a student indicated that addition and subtraction problems were easy for her, but that multiplication of decimals was difficult. The instructor had her select an example of a word problem that involved multiplication of decimals, and then conducted a WPP analysis of the problem. As the instructor and the student went through the steps, attention was drawn to the importance of certain words in the problem and how attention to these words could lead to the correct representation of the problem. The instructor also pointed out that, although he agreed that the computational aspects of the problem were complex, discovering the correct representation was fairly simple. In this way, the instructor validated the part of the solution process that the student was capable of performing without criticizing her for not finding the correct answer.

This latter point is important for several reasons. First, it confirms the findings of researchers such as Chamot, Dale, O'Malley, and Spanos (1992), which suggest that students in classrooms that utilize learning strategy instruction are able to develop metacognitive skills even if they lack the ability to find the solutions to word problems. Secondly, it confirms the contention of Pressley and Associates (1990) that learning strategy instruction should focus on a few strategies at a time and that the instruction needs to proceed over an extended period of time. In the case of students such as those studied here, for example, focus on selective attention is of great importance since they need to be able to identify vocabulary that relates to the solution. If they can learn to do this, then they are at least learning a valuable reading technique even if they are unable to achieve a solution.

T?In some cases, students who had successfully solved problems failed to circle any of the items on the checklist. In others, students who had not been able to solve the problem, circled several items. In these cases, it was a simple matter for the instructor to ask the students to explain their selections or lack thereof. This made it possible to remind successful students that they had correctly used specific tactics and strategies thus helping them to make the connection between problem solving and planning. For unsuccessful students who nonetheless circled some of the items, the instructor was able to determine whether they were simply circling without thinking or if their choices had an underlying rationale. For example, if students chose item 1 ("I looked for important words..."), the instructor asked what words they had circled, if they had found the meanings of the words, and whether there were other words which they would have circled in retrospect.

How Is the Role of Learning Strategy Instruction in this Acquisition Process Measured?

We have seen that we can use procedures such as the WPP to create contexts for students to use learning strategies in acquiring content. But can we measure any role that the learning strategies might have in helping students to acquire mathematical knowledge?

Research by Chamot, Dale, O'Malley, and Spanos (1992) found benefits for students in classrooms taught by HILT Math teachers who participated extensively in CALLA training activities and who incorporated learning strategy and problem solving activities into their lessons. Significantly more students in these classrooms than in other HILT Math classrooms scored correctly on a sample problem used in the research study. Moreover, they found that, when asked to think aloud about their solutions, students in these classrooms mentioned the correct sequence of problem solving steps more often than students in other classes. Finally, as discussed in the last section, these students also mentioned significantly more metacognitive strategies than did the other students.

Data from a follow-up study are currently being analyzed, but we can cautiously conclude that learning strategy instruction in the form of procedures such as the WPP helps language minority students solve problems by giving them greater control over the learning process. Although the mere adherence to a prescribed series of steps is not sufficient to solve word problems correctly, it does offer students a disciplined way to proceed. In addition, it provides multiple opportunities for them to work cooperatively with their classmates in practicing both language and content.

Method: Science Case Study

Subjects

There were 12 students in the HILT B Science class at the end of the school year. As mentioned earlier, this was a dropout prevention class that was limited to 15 students. The students had four periods of HILT Science per week, and a fifth period was reserved for group counseling. Enrollment was stable through the year, with only one student entering class later than September. All of the students were speakers of Spanish. Nine were from El Salvador, one from Honduras, one from Guatemala, and one from Mexico. All were at the HILT B English proficiency level; they ranged in age from 15 to 18 years. Two students were ninth graders, and the remainder tenth graders. Eight of the students had entered the project high school as new arrivals in September 1990. Three had come in the spring of 1991, and one had come in September 1989.

HILT B students range between the second and fourth grade in reading level. They are able to write short paragraphs, but with numerous lexical and grammatical errors. Compared to HILT A students, however, they are more capable of engaging in classroom discussions, reading textbooks, and comprehending instructor explanations.

Instruments

In October 1990, the author developed and began to use a Scientific Method Procedure (SMP) in order to enable students to practice presenting their scientific knowledge in terms of the steps of the scientific method suggested in the course curriculum guide. Like the WPP, it invites students to utilize learning strategies and tactics in a systematic manner. The format is as follows:

NAMES

DATE

Scientific Method Procedure

1. State the problem. (What are we trying to learn?)
2. Gather information about the problem. (What do we already know?)
3. Form a hypothesis. (What do you think will happen? Why?)
4. Perform an experiment to test the hypothesis. (How will we learn?)
   a) materials used:
   b) steps in the experiment:

5. Record and analyze data from the experiment. (What happened? Why?)
6. State a conclusion. (What have we learned?)

Like the WPP, the steps of the SMP require the students to process information in a manner that integrates language practice, content learning, and the application of learning strategies and tactics. The SMP is used in conjunction with experiments from the texts and supplementary materials that either contain information or request students to find information needed to fill out the SMP. Students fill out the forms either as they are doing the experiments or as a review activity after they have finished the experiments. Since they are at a higher reading level (between grades 2 and 4) than the HILT A Math students, and also more sophisticated in terms of their familiarity with cooperative learning and other ESL classroom techniques, the author has found it unnecessary to include explicit steps dealing with selection of partners or using resources.

Students use metacognitive strategies such as selective attention by attending to key questions and types of information (all steps) and organizational planning in setting forth the materials and experimental steps (Step 4). They use cognitive strategies such as elaboration in relating new information to prior knowledge (Step 2) and inferencing in predicting the outcome of the experiments (Step 3). They use social-affective strategies such as cooperation in working with their peers (all steps) and questioning for clarification in eliciting additional explanation from their partners (step 6).

As with the WPP, the SMP is followed up with a Learning Strategies Checklist and Student Self Evaluation form tailored to science:

NAMES

DATE

Science Learning Strategies Checklist

There are many learning strategies that you can use when you follow the steps of the scientific method. Check the two or three things that you did most when you worked on the last experiment.

A. I carefully observed while my teacher or partner did the experiment.

B. I used information I already knew to make decisions, form a hypothesis, or draw a conclusion.

C. I took careful notes while my teacher or partner did the experiment.

D. I asked questions of my teacher, partner, or myself while doing the experiment.

E. I made inferences or tried to predict what was going to happen.

F. I used my textbook or other resources to help do the experiment.

G. I tried to think of other ways to do the experiment.

H. Other (please explain)

NAME

DATE

Science Student Self Evaluation

These are two important things I learned in science today/this week/this month/this quarter/this semester/this year:

1.___________________________

2.___________________________

This was an easy topic for me:

This was a difficult or confusing topic for me:

Name an experiment that you can do:

What did you learn from this experiment?

I need more help with:

This is how I feel about this experiment/topic: (circle words that are true)

successful, confused, relaxed

interested, bored, excited

happy, worried, other:____________

This is where I got help: (circle the words that are true)

my teacher, my friend or classmate, my parents

Procedures

Students were given the SMP four times in May and June 1992. The 44 minute classes were devoted almost entirely to completion of the SMP, the checklists, and the evaluation forms. They were instructed to pair off and to engage themselves in a series of experiments selected by the instructor from their laboratory resource books (Roderman, 1987, p. 75-76). The experiment selected for discussion here asked the question, "Why does a fire need oxygen?" Pairs of students were given a worksheet which asked this question. Each pair was given two votive candles, two dishes, a book of matches, and a small glass jar. The worksheet instructed them to light each candle, and to wait until the flames got big. Then they were to place a jar over one of the candles, watch what happened, and then answer the questions: "What happens to both candles?" and "Why?" As students worked on the experiments and the SMP, the instructor circulated and provided assistance as requested. Spanish-English dictionaries were available if students needed them.

The experiment was related to one the students had done during the fall semester, at which time they also completed an SMP form. The point of the fall experiment was to show how fire consumes oxygen in order to burn. Students used cans of sterno and votive candles to see which were extinguished more quickly when placed under a jar. Data from both the fall and spring sessions are included here for comparative purposes.

The author has investigated the same four questions asked in the math case study, again selecting responses to each step of the procedure. Since science is experimental by nature, he was particularly interested in noting student ability to express hypotheses, draw inferences, and make predictions. In addition to having students fill out checklists and evaluation forms for each experiment, he also had them fill out evaluation forms for the month of May and for the entire year.

Results: Science Case Study

The science students were more cooperative, more responsible, more confident, and more diligent than the math students. They worked faster and were more accurate in both their English and their explanations of scientific principles. They were easily able to complete the SMP, the checklists, and the evaluation forms in one class period. On their responses to the evaluation forms, they frequently indicated that they felt successful, interested, or happy. They also checked more items on the checklist, frequently checking four or five choices, whereas the math students rarely checked more than two.

Step 1 (State the problem). Although the problem was clearly stated as a question at the top of the lab worksheet, students did not simply copy this question. Instead, they attempted to follow the SMP directions. Thus, for example, whereas the lab worksheet asked, "Why does a fire need oxygen?" pairs of students wrote the following questions or statements:

> We were trying to learn how the oxigen work.
>
> We trying to learn how we can use fire.
>
> We were trying to learn, when we burn something they also use oxygen.
>
> we are trying to learn how fire needs oxygen.
>
> We are trying to learn If the fire can stood with out oxigen.

All of the statements contain English errors, but they are comprehensible. They are also appropriate since the SMP asks students to state the problem.

The first two statements seem off the mark in terms of expressing the point of the experiment. The third statement is more accurate because it relates fire (burn) to oxygen. The fourth statement is better because it relates fire and oxygen and indicates that a process (how) is in question. The best statement, however, is the last one, which also contains the most glaring English error (If the fire can stood). These examples are interesting because they reveal how difficult it is for limited English proficient students to express scientific facts in L2. A teacher must be able to assess whether or not a student has missed the point, made a grammatical mistake, or both.

Step 2 (Gather information). Students demonstrated that they had prior knowledge of the relationship between fire and oxygen through the following responses:

> We already know when we put a candle in to a jar it had minus oxygen.
>
> I already know if I burn something that can't get oxygen that thing can't burn.
>
> that the candle inside the jar got less oxygen than the other candle.
>
> We know that with no oxygen fire can't stay alive and with oxygen can stay alive.
>
> We know that faire need oxigen.

Each of these responses suggests that the students understood the principle that fire consumes oxygen in order to burn. Students might have known this from daily experience, but they also could have recalled the results of the fall experiment. The responses seem more convoluted in grammar than the responses to Step 1. This is perhaps an indication that students had something complex to say, but were unable to do so through their limited English. For example, the writers of the first response used the expression, “it had minus oxygen” when they probably wanted to say something like, “it consumes the oxygen until it runs out of fuel and goes out.” Their response was a creative, if infelicitous use of English.

Step 3 (Form a hypothesis). The instructor placed great emphasis on this step. It is interesting to compare student responses from the fall and spring because we see an improvement in their ability to state hypotheses. The following responses were selected from the work of a pair of students who worked together both semesters:

> *Fall:* Well, the fire of candle is small and it take more time to use the oxigen. So the sterno Fire is bigger It take a few minute to eat the oxigen.
>
> *Spring:* We think the candle is inside the jard won't stand for a long time.

Notice that the fall response is not a hypothesis at all. It uses the simple present tense to report the facts. The spring response is a prediction: it reports what the students believe will happen to the candle. While both responses contain English errors, the instructor was able to praise the students in the spring for using the simple negative future tense to state a hypothesis.

Another pair of responses that indicates even more dramatic progress is the following:

> *Fall:* was because the oxigens was more longer that the other one.
>
> *Spring:* we thing that the candle inside the jar won't stay lited as long as the other candle because the jar doesn't have a lot of oxygen.

Although grammatical and lexical errors are present in the Spring response, it is clearly superior to the fall response. It is a prediction, whereas the other is a vague sentence fragment in the simple past tense

Step 4 (Perform experiments). In this step, students first had to list the materials and then describe how to conduct the experiment. Two of the more interesting descriptions were selected from the spring session:

> First light each candle. Wait a minute, until the flame get big then put the jar over one of the candles and watch what happens to the flames.
>
> I pull the candles on the dishes and then we pull fire to the candle and then we cover the candles and the candless turn off.

These examples are interesting because the students paraphrased instructions printed on their lab resource sheets. They could have simply copied, but chose instead the riskier course of using their own words. The results were not perfect, but they provided the instructor with contextually appropriate text which could be applauded for accuracy of thought, but corrected for inaccurate English.

Step 5 (Record and analyze data). In this step, students were supposed to explain what happened. This gave the instructor an opportunity to look for student misconceptions regarding the relationship between fire and oxygen. The following responses were selected from the work of the same pair of students in the fall and spring sessions:

> *Fall:* The candle has more oxygen that the sterno but the fire of the candle is more soft that the sterno because we know that the sterno has mor vapor.
>
> *Spring:* Whe we put the jar to cover the candles the candles turn off because the air was gone, because the vapor absorve the air that what happend.

The fall response does not really state what happened; moreover, it suggests a misconception—the students did not seem to realize that the fire went out because the candle and the sterno consumed the oxygen in the jar. Thus, they were surprised when the sterno in the jar went out faster than the candle in the other jar. The reason, of course, was that the sterno burned more intensely, required more oxygen and, therefore, depleted the supply in the jar faster. According to the logic of their misconception, however, the sterno was stronger and therefore should have lasted longer. The spring response provides an explanation and clearly indicates that the students knew that the heat of the candle had consumed (absorved) the air.

Step 6 (State a conclusion). The main differences between the fall and the spring sessions were that more students responded to Step 6 in the Spring and their responses tended to go beyond the specific facts of the experiment to a more general conclusion about the importance of oxygen. For example:

> We learn that we need oxygen to make fire. The jar didn't have enough oxygen that's why the fire couldn't stay on.
>
> We already have learned when we need more oxigen and is very important for us.
>
> We learned that If in the Industry doesn't have oxygen It can have fire to work.
>
> that you cannot make fire without oxigen,

> We learn if in the place where we are not air we can't make fire because the air make fire thing that are natural.

All but four of the pairs checked Item B on their learning strategies checklists indicating that they had used prior knowledge to help them form a hypothesis or draw a conclusion. The instructor conducted a classroom discussion in which he asked the students to be more specific about how their prior knowledge led to the hypotheses and conclusions they had drawn. For example, the instructor asked the writers of the second response to be more specific about why fire was important, and the writers of the third response to name some industries that depended upon the use of fire. The ensuing classroom discussion gave the students the opportunity to practice their English in the context of a scientific principle that had practical applications. Moreover, it validated the students' hypotheses, conclusions, self-evaluations, and application of learning strategies.

Discussion: Science Case Study

The results of the SMP sessions reveal that the HILT B students were successful in processing what they had learned in the classroom experiments in terms of the steps of the scientific method. The instructor noticed a budding sense of purpose and confidence among the students, who worked together well and were eager to report their findings to the rest of the class. The linguistic, academic, and strategic aspects of the implementation are discussed below in terms of the four questions posed in the introduction to the case studies.

What Are the Linguistic Demands of the Scientific Content?

Neither the textbook nor the lab resource books were very challenging linguistically, and the use of pictures, diagrams, and concrete materials made it easy for the students to visualize what they were learning. But the ability to paraphrase and summarize the information was a challenging task for project students. The SMP invited them to recast this information into their own words using whatever structures and vocabulary they had in their English repertoires. They had to practice with forms used to report scientific information; this gave the instructor the opportunity to correct errors and suggest alternative modes of expression while complimenting their knowledge of the content and their ability to complete the experiments. The students developed a positive attitude toward correction of their English errors as evidenced on their evaluation forms for the year and for the month of May. Several students indicated that they needed more help with vocabulary, writing, and grammar, but that they had found the content to be easy. The instructor suggested that they rewrite some of their hypotheses and conclusions and gave them model sentences and vocabulary to work from. Thus, correction became a natural outgrowth of student writing and thinking. One benefit of the SMP, then, is that it allows the instructor to capture student responses, to question students about their meaning, and to correct their English to convey their knowledge and intentions.

How Is Student Acquisition of the Science Content Assessed?

The content, which the students were expected to learn, included both knowledge about scientific concepts and principles (declarative knowledge), and knowledge of how to apply their skills in experimental activities (procedural knowledge). The SMP facilitated the instructor's ability to assess both types of knowledge because he was able to examine student replies both in terms of conceptual accuracy (the declarative side) and in terms of their ability to follow the format (the procedural side). For example, in the responses cited for Step 3 above, the instructor was able to determine that the students understood that fire consumed oxygen in both the fall and the spring sessions, but that only in the spring did they know how to express a hypothesis. He could therefore assess both their declarative and procedural knowledge and help them appreciate the difference between the two by showing them examples of their own work.

The SMP is thus useful as a performance assessment instrument (see Kulm and Stuessy, 1991) because the instructor is able to examine student responses to see if they have synthesized prior knowledge with new information taught in relation to scientific topics, and if they have made connections to real world experiences. In an experiment involving the use of an inclined plane, for example, one student gave an insightful explanation of the utility of ramps because he had experience moving furniture. He, therefore, knew first hand the advantages of using a ramp to help lift furniture and was able to bring this prior knowledge to bear in predicting the results of the classroom experiment and connecting the experiment to the real world.

How Can Teachers Provide Contexts for Students to Utilize Learning Strategies in Acquiring this Content?

The SMP data indicate that an effective way to involve students in the use of learning strategies is to provide an integrated plan for learning. Like the WPP, the SMP is itself a learning strategy in the sense of being a complex plan. When the students attempt the various steps, they are required to use specific tactics such as elaboration, selective attention, and questioning for clarification. Once the students have completed their work, the instructor can review their performance with them and choose to point out features of their language development, content learning, or use of learning strategies. Whereas the SMP implicitly and indirectly invites the use of learning strategies, the follow-up sessions enable the teacher to be explicit and direct in pointing out what the students have done.

At the end of the final SMP session, the instructor returned all of the student worksheets (he had been keeping the students' work in individual portfolios) and asked them to complete checklists and evaluation forms that covered the four experiments they had done in class. When they were finished, he conducted individual interviews with each student asking them to refer to their portfolios to clarify the checklists and evaluation forms. The interviews focused upon student perceptions of their learning both in terms of what they had learned (declarative knowledge) and what they had learned how to do (procedural knowledge). The instructor was able to introduce learning strategy terminology in relation to what the students had learned to do procedurally. Instead of using technical metalanguage such as “resourcing,” “inferencing,” “selective attention,” and so on, the instructor simply asked questions such as: "What resources did you use?" "What can you infer from this experiment?" and "What words or information did you have to pay attention to do the experiment?" This provided a vehicle for the instructor to integrate learning strategy instruction with content and language learning rather than isolating the learning strategy instruction and making it an end in itself.

How Is the Role of Learning Strategy Instruction in this Acquisition Process Measured?

Precise specification of the most effective strategies and tactics to use in different content-ESL contexts, and verification of the types and extent of knowledge acquired though procedures such as the SMP await research of the type described in relation to the math case study. We have, however, seen evidence that the science students applied metacognitive, cognitive, and social-effective strategies and tactics. They planned for their learning through paraphrases of the problems and statements of their prior knowledge. They also manipulated their learning through the statement of hypotheses and conclusions, elaborated upon new ideas, and related these ideas to the outcomes of the experiments. Moreover, they worked effectively with their partners and teacher by asking intelligent questions and demonstrating the beginnings of a critical attitude. The SMP thus provided a procedural framework for students to apply specific tactics and strategies which in turn could facilitate acquisition of scientific knowledge. By giving them control over the learning process, it provided multiple opportunities for content acquisition.

Conclusions and Recommendations

In the introduction, four questions were raised regarding the education of students of limited English proficiency. In closing, each question is addressed and recommendations are made regarding the implementation of content-ESL programs.

How will these students develop the linguistic proficiency necessary to deal with classes which presuppose advanced communication skills?

The performance of the math and science students in following the WPP and SMP indicated that students could learn to apply learning strategies and tactics in learning language and content. The procedures helped students develop confidence, discipline, and responsibility in conducting experiments and solving problems. In the case of the math students, the primary benefit seemed to be related more to classroom management, study skills, and critical thinking than to language or content learning per se. The linguistically more advanced science students were also able to practice more sophisticated language skills such as recording data and stating predictions, hypotheses, and conclusions.

However, it would be dishonest to suggest that the procedures and techniques used by the author were sufficient to raise students to the level of linguistic competence presupposed by mainstream educators when they argue for increased mathematical and scientific literacy. We should be careful not to underestimate the amount of time and preparation it takes for students to develop academic language proficiency. We should therefore develop well-articulated programs for language minority individuals that involve the participation of mainstream mathematics and science teachers at all stages of development, and which include attention to language acquisition at all stages of the learning process. Careful screening of students should be conducted to account for variations in L1 literacy and previous schooling in both L1 and L2 contexts. Some students will benefit from placement in a bilingual program which teaches them basic skills in math and science. Others will benefit from the types of classes described here. Still others will be better suited for transitional or mainstream classrooms taught by math and science instructors trained in ESL methods and multicultural education.

While students with limited English skills might be able to succeed in math and science classes that ignore or pay lip service to discourse and communication, they will find themselves a step behind their more mathematically and scientifically literate classmates in classes that take the reform movements to heart.

What preparation will teachers need to provide effective instruction?

Language teachers should be trained to integrate language and content instruction. Moreover, they should be willing to teach content-ESL courses and to collaborate with mainstream math and science teachers in their development. Content teachers should be trained in ESL methods, multicultural education, learning strategy instruction, and the integration of language and content instruction. It is particularly important that they be aware of what techniques and materials their ESL colleagues are using. They should reinforce techniques such as cooperative learning and learning strategy instruction, which require practice over time, and should incorporate the use of bilingual dictionaries and content-ESL materials to help students overcome their linguistic limitations. They should also learn to use performance assessment techniques such as the keeping of portfolios since it is especially useful to have a record of student progress in expressing math and science concepts in their new language.

The ideal way to provide this training is through a team approach. Language and content teachers from the same school should be trained together and engaged in follow-up activities such as technical team meetings and development projects. It should not be assumed that the curriculum will remain static once developed; there will be inevitable revisions suggested by teachers or necessitated by changes in school or district policies, personnel, or population.

It is highly desirable that the trainers be classroom teachers themselves, preferably in the same school or school district as the trainees. The author has learned from personal experience that math and science teachers are extremely wary of outside "experts" who are hired for special training sessions and never seen or heard from again. Since they are under pressure from within their own disciplines to reform their teaching, they must be highly selective of which activities to undertake. If the trainers come to them from within the framework of their own school or district, there is a greater chance that they will sense a commonality of purpose and need and, therefore, agree to participate.

How will schools have to change in order to accommodate cooperative relationships between language and content teachers?

Lucas, Henze, and Donato (1990) discuss eight features of high schools that promote the achievement of language minority students. Four of the features involve staff development, course and program variety, counseling, and parent education. While the author agrees that each of these features is necessary, they are not individually or mutually sufficient to ensure cooperation between language and content teachers or eventual student success. It is one thing to design a high school program for language minority individuals that exhibits the features extolled by advocates of content-ESL or bilingual education; it is quite another to maintain a program in which both language and content teachers and their respective departments coordinate their efforts to see that students receive ongoing language practice within the context of their math and science classes.

Priorities change and budgets shrink, arming school boards with reasons to underestimate or ignore student needs and the arguments of reformers. Without the vigilance of the real experts—the teachers and the school administrators—these needs and arguments are easily forgotten. The impetus for change must, therefore, come from within the schools and school districts themselves, communicated by the teachers to the principal, whose awareness and approval greatly improves the chances that individual departments will cooperate and that supervisors and school boards will find funding for the changes. One way content-ESL teachers and advocates can effect change is to link their efforts to those of their colleagues and supervisors. For example, the author has taken advantage of opportunities to join school committees to argue the merits of content-ESL and linguistic and cultural sensitivity. He has also made colleagues in the math and science departments aware of the reforms suggested by leaders in their own disciplines and presented them with readings which tie these reforms to the needs of language minority students. Articles co-written by language and content educators (e.g., Santiago, and Spanos, 1993; Dale and Cuevas, 1992) are useful because they model the collaborative teaching behaviors that we wish the teachers to adopt. While not all teachers and administrators have been responsive, enough have shown an interest to create a meaningful dialogue within the school community.

What kinds of research will help to facilitate these new relationships?

Although teachers are often too busy to attend to scholarly research, the author has found that they are interested in research conducted by colleagues within their own schools and school districts. A case in point is research by Chamot, Dale, O'Malley, and Spanos (1992) cited earlier. Since the research took place at district schools, the teachers had a stake in the results. In many cases, they also had a hand in the research itself since they were asked to provide input and assistance at the planning, implementation, and analysis stages.

Further research that would be a useful follow-up to this study would involve evaluation of student progress in language development, content acquisition, and learning strategy usage for content-ESL classrooms. Special attention should be paid to differences between different levels of language proficiency and content mastery for both math and science, as well as to variations between the performance of middle and high school students. It would be highly advisable to study variation between stable classes and classes with high student mobility to see if there are any effects on student achievement. For example, it would be interesting to see how a stable HILT A Math class did in comparison to a HILT A Math class such as the author's 1991-92 class, which was reconstituted midway through the year. It would also be revealing to see how the author's students do in HILT General Math compared to students who enter from stable 1991-92 HILT A Math classes. Finally, analysis of student WPP and SMP portfolios and protocols would give insights into language, content, and strategy acquisition that could be used to inform placement efforts and future curriculum development efforts.

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